Oceans and Climate, and Human Health Impacts

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U.S. Senate Committee on Commerce, Science and Transportation
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Climate change takes on real force when it combines with human activity. It produces multiple and compounded changes of the physical environment, and of ecosystems. The US feels these impacts from beyond national boundaries, from the global atmosphere and ocean.

There are many points of contention: between modification of our environment and accommodation to it; between natural and human-induced climate change; within the scientific debate, between the need for prediction and the need for diagnosis. Improved observation and understanding of the current and past states of the environment (the atmosphere, ocean and land surface) may be just as important as attempts to predict its future.

As Dr. Schmitt has earlier this morning described, the ocean plays a particularly interesting role in climate: it dominates the storage of heat and carbon and water; it also contains a significant fraction of global biological activity: photosynthesis and respiration. It is a well-spring of diversity, harbors newly discovered forms of life, and in the search for natural pharmaceuticals it is richer than the land.

Large-scale oscillations of climate. el Nino/Southern Oscillation (ENSO), centered in the tropics, is an ‘argument’ between ocean and atmosphere which radiates across N America. With enormous impact on temperature, rainfall, storms, flooding, drought, there is some good news in an el Nino winter, and much bad news.

In the far northern Atlantic Ocean, the paths followed by intense storms over the ocean have moved north since the early 1970s. These storms intensify as they suck heat from the ocean. This is a part of the so-called North Atlantic Oscillation (NAO), which can switch regimes from one month to the next, or from one 30 year period to the next: it has an element of unpredictability. It is intimately related to the jet stream and polar vortex, a ‘tall’ mode that reaches to the stratosphere. The NAO is one of several important patterns of oscillation of the atmosphere outside of the tropics (others include north-south ‘annular oscillation’ of the jet-stream system in the Southern Hemisphere, and a great wave round Antarctica that appears to be coupled between ocean and atmosphere).

In addition to its many impacts on weather, drought and flooding, the NAO is involved in the great, deep overturning circulation of the ocean. The temperature and salinity of the oceans both condition its fluid density...its ability to sink. It is at high latitude that the ocean is chilled by the atmosphere, and in rare and small regions, water sinks to the abyss. This global system fulfills the need for heat to be transported from the warm latitudes to the cold, where it radiates to space.

Nearly horizontal layering of the oceans, with dense waters sinking beneath buoyant surface waters, is the result of this ‘heat engine’ and it is of great consequence to the distribution of ocean life. Photosynthetic life needs sunlight and nutrients. By controlling the flow of nutrients from their rich store at depth, upward to the sunlit surface, life of the ocean is determined by its patterns of its up/down, north/south circulation. This ‘meridional overturning circulation’ provides a severe challenge to computer models, because of the small yet essential features and the complex shape of the solid Earth. While current computer models have many inaccuracies, they are increasingly being subjected to the acid test of focused, small scale seagoing observational programs.

ENSO and NAO are examples of the possible expression of global warming in ‘modes’...that is patterns of ocean and atmosphere response with warm and cold, wet and dry. The Titantic sank in 1912, during a cold period that encouraged icebergs to reach southward into shipping lanes. There followed two major periods of global warming this century, the 1930s-40s and 1970s-90s, which in fact correlate with phases of the NAO. These modes are good tests of computer models of climate, and indeed are the subject of intense simulation work at present.

Northern Asia and Canada experienced some of the most intense warming in the 1990s, dominating the global average: we in the US have not yet seen the full force of warming. The northern Atlantic actually has cooled for many years, as cold, Arctic air blew from Canada with increased vigor. Greenhouse warming is expected on average to be initially severe in the Arctic, and to increase the water vapor in the atmosphere. In N America, increased precipitation and streamflow out into the ocean has developed. Together with the long feared, and now observed, thinning and meltback of the Arctic sea ice, these events are portentous.

Abrupt climate change. The paleoclimate observations, both from sea-floor sediment cores, glacial ice cores, record remarkable periods of rapid change in the distant past, particularly during ice-age glaciation and the transition out of it. Both the increasing input of fresh water on top of the ocean, and the warming itself, can resist the sinking and global deep circulation described above. Communication between land surface, Arctic, and Atlantic ocean is important to the distribution of low-salinity water, and it is correlated with the NAO. Mathematical models and computer models of climate predict a slowdown, by up to 50%, of this global circulation in the coming decades. Such changes can be called *abrupt* in the great scheme of things. A new National Research Council study on abrupt climate change is underway this summer.

The ocean ecosystem represents an important, in some ways dominant, part of global photosynthesis and respiration. Ocean circulation and its layering into dense deep waters and buoyant surface waters largely control the distribution of life in the sea. Disappearance of cod from Atlantic fisheries has a strong relation to over-fishing, yet these fish are very sensitive to temperature. Recovery of cod stocks has been slow, even when fishing grounds closed down. Salmon fisheries in the north Pacific have seen very long (~50 year) cycles, under a multitude of pressures from declining quality of rivers and streams, and climate change (the so-called Pacific Decadal Oscillation, or PDO). This summer Coho salmon returned to Lake Washington in great numbers, for the first time in a decade, yet other salmon species are now on the endangered list. Overall, 11 of the 15 most important global fisheries are in trouble, and the world fish catch has begun to decline after rising six-fold between 1950 and 1996. It is a classic case of compounding of causes: over-fishing puts stress on fish populations, making them sensitive to modest climate change.

Storms. Severe storms, hurricanes, tornados, the super-novae of weather, are of particular importance. Loss of life in underdeveloped countries and economic loss in the US are both striking. A tropical cyclone (dynamically similar to a hurricane) in the Indian Ocean hit land in Bangladesh in November 1971; its 30 foot-high storm surge inundated the low-lying river delta, causing between 250,000 and 500,000 fatalities. In the US Hurricane Andrew, in 1992, was one of the most costly natural disasters in history. A direct hit of a major hurricane on Miami could cost more than $70B in property damage, owing to the intense coastal population increase and development of coastal real estate. Hurricane Mitch, in 1998, showed the world how capricious and destructive these storms are in the less-developed world. Following an unexpected path southward, then sitting over the mountains of Honduras and Nicaragua, Mitch destroyed villages and cost more than 10,000 lives through endless rainfall, flooding, and erosion. It nearly destroyed the economies and social infrastructure of these countries.

Hurricane paths and their intensity are correlated with el Nino cycles, and with another key tropical oscillations, the Madden-Julian Oscillation. Hurricanes (and tropical cyclones) take their energy from the heat of the tropical ocean. They do so surprisingly rapidly, and have been observed to intensify in passing over the Gulf Stream and warm eddies (only 50 miles wide) in the Gulf of Mexico. Long lasting effects are inland flooding, pollution and sedimentation, which destroy habitats in estuaries and marshes. Their connection with global warming is less clear. Model studies suggest a 5%-12% increase in hurricane wind-speed for a 2 degree C rise in sea-surface temperature, but this is very uncertain.

Changes in normal weather, for example, more intense rainstorms, have been linked to ENSO, NAO and other global climate modes. Possible links exist back to global warming through these modes of oscillation, as well as more directly, through the changing levels of cloudiness.

At every turn in this discussion we must weigh the relative advantages of prevention, protection, and treatment in the aftermath. Amartya Sen, an economist at Cambridge University, argues that destruction from climate and storms is most severe in the aftermath: that stockpiling of food and creation of jobs programs for the poor are important in preserving human life...as much so as protection from the storm on the day, itself.

Coastal Ocean. The coastal ocean, the water on the continental shelves and in estuaries, is a small part of the global ocean, yet is the home of roughly one half of oceanic biological productivity (roughly 25% of global primary biological productivity). It is the site of much diversity, and close involvement with human populations, which are increasingly concentrated near the seacoast. It is also the site of 80 to 90 percent of the global fish catch. Estuaries, where rivers meet the sea, are a sort of pumping machine in which river-flow and tidal stirring combine to suck water in from the deep ocean, supplying the region with nutrients: to their benefit, estuaries flow in and out at rates much greater than (as much as 50 times) the river-flow that drives them. Nutrient sources from rivers are often a small contribution, yet in some estuaries, agricultural practices are loading the estuaries with nitrogen and phosphorus, as well as viruses and bacteria. Chesapeake Bay seasonally teeters on the edge of hypoxia, a reduction of oxygen to the point where fish can no longer live, when stratification, layering of the water by density, and nutrient inflow are both high.

The coasts are what we call 'potential vorticity guideways' along which climate change can be signaled rapidly (for example, from an el Nino event on the Equator, poleward along the North and South American Pacific coasts). With a complex of local influences, human and natural, the coastal ocean is undergoing rapid change. Yet, at the same time, global climate change is strongly felt in this region. A third, severe effect is the colonization of the coastal ocean (and lakes and rivers) by new species introduced by ship traffic. Ships carry ballast water from one continent to another, discharging it and its biological cargo near the coast. The highly diverse coastal ecosystem, after evolving in relative isolation, is suddenly invaded.

It is hard to say in detail what is the time- and space- variability of ocean biology and its impacts on the health of humans, fish and algae. This is because we have not yet invested in baseline observations of the coastal ocean. But we observe numerous regional hot-spots, as with the dinoflagellate *gymnodinium catenatum* transported to Australia from Asia, and the Asian clams that have taken over San Francisco Bay.

Both river- and deep-sea inputs to estuaries change with climate. For example, during El Nino, riverflow decreases in some regions, thus decreasing the nutrient supply from this source. At the same time coastal winds change and this change can alter the supply of nutrients to the estuary as more or less nutrient rich water is pulled up from the deep ocean to the estuary mouth. Variation of the health of fisheries, such as oysters in the Pacific Northwest, has been shown to depend on the frequency and strength of El Nino. Because of the link to offshore waters, estuaries can also be expected to show evidence of longer term climate change such as the PDO.

Major rivers can exhibit these sensitivities strongly. In the Pacific Northwest the largest river is the Columbia. The plume from the Columbia can stretch several hundred kilometers from the river mouth--to the Strait of Juan de Fuca in the north and to San Francisco in the south. The size of the plume is controlled in spring by the amount of snow pack received by the region in the preceding winter. For example, snowpack was high in 1999 during La Nina. In such years, the plume floods other nearby estuaries, substantially reducing the salinity and nutrients in those estuaries, dramatically altering the environment encountered by emerging salmon smolts and entering juvenile crab larvae. In years with lesser snowpack, the Columbia plume likely has a more southwestward orientation and may have much less effect on local estuaries. Long term effects on the fisheries might be expected due to these and other such climate effects and are the subject of current research

Human health. Along with colonization of the coastal ocean by new species there are increasing problems involving toxins. Harmful algal blooms are occurring more frequently. They involve both local human causes (nutrient loading, turbid water), and physical ocean changes (temperature, stratification, upwelling, rainfall). While mortality is not often widespread, illness and economic loss from closure of shellfish beds is. Estimates of the loss to the fishing industry from a single *Pfiesteria* outbreak, in Chesapeake Bay in 1996, were $20M. The degree to which global climate change is involved, is not yet known.

An example of a pressing public health and economic problem is the diatom in the genus *Pseudo-nitzschia* that cause domoic acid poisoning (DAP), also known as amnesic shellfish poisoning (ASP), and dinoflagellates in the genus Alexandrium that are the source of paralytic shellfish poisoning (PSP). Toxic outbreaks along the US coast can be highly localized or can extend over several hundred miles and last for several months. Both the occurrence of such toxic algal blooms in the offshore coastal waters and the delivery of the toxic algae to coastal beaches and to coastal estuaries is thought to depend on wind speed and direction as well as coastal water properties and hence have a direct link to climate changes along the US coast. Near the Strait of Juan de Fuca, the physical oceanography of the coastal circulation has been linked with the appearance of HABs at the coast. A detailed study of the toxic dinoflagelate *gymnodinium breve* shows its development in the warm, broad shallows of the Gulf of Mexico, and its transport in the Gulf Stream system as far as North Carolina, where it has come to shore.

A major outbreak of cholera developed in coastal Peru, during an extended el Nino event in 1991, and thereafter quickly appeared to neighboring countries. In the first 3 weeks, 30,000 cases and 114 deaths were reported. Cholera lives dormant in the sea as *vibrio cholerae,* associating itself with mucous membranes of the copepod. There is an apparent relationship between warm sea-surface temperature and cholera there and in Bangladesh. The association of climate with disease is thus plausible, yet there are several possible routes, for el Nino rainfall alters sanitation on shore as well as disturbing and warming the coastal ocean.

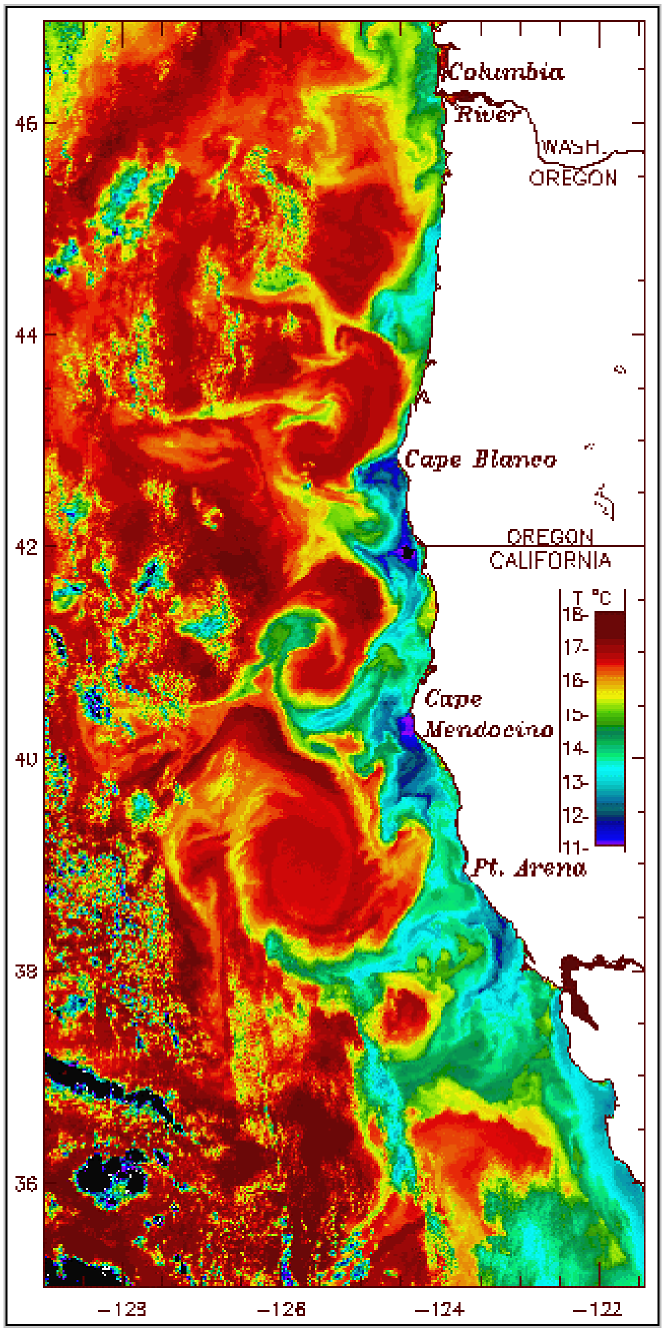
Cholera is a disease that may illustrate the association of virulence with transmission rate. In evolutionary biology, Paul Ewald of Amherst College argues that cholera and many slowly developing human diseases have evolved so as to maximize their own transmission. Thus, with poor sanitation in the under-developed world, cholera is rapidly transmitted and very virulent. In countries with good sanitation cholera exists in a much more benign strain, adapted to very slow transmission. This message suggests that global climate change and human activity (like introduction of ‘exotic’ species by ship traffic) both could conspire to increase the virulence of toxic viruses and bacteria in the environment.

There is a tension throughout this debate on global change, between advocates of public health, social infrastructure, economics of the recovery on the one hand, and advocates of mitigation of climate change (and its role in disease), and environmental science, on the other. Regardless of the balance struck in resolution of this debate, there is value in observing our environment, predicting its future, AND assessing its current behavior.

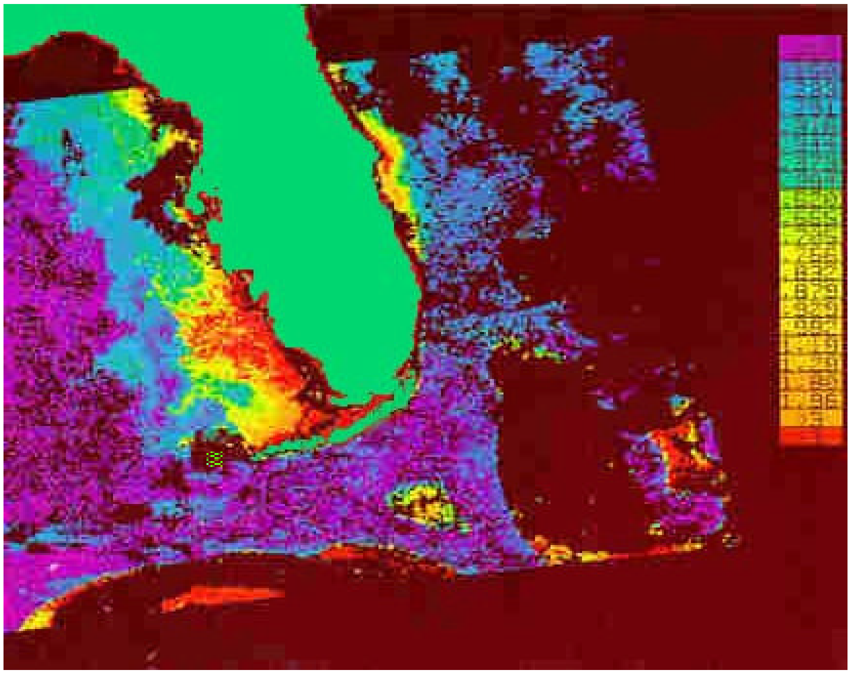
New technologies. A remarkable chain of technological discovery has focused on observations of the global environment. These are moored and drifting and self-propelled vehicles in the ocean, with a range of sensors for physical, biological and chemical substances; orbiting satellites that probe both oceans and atmosphere; sea-floor and moored ‘observatories’ that allow us to ‘explore in time’ as well as space. The importance of establishing long-term measurement sites for climate studies cannot be overstated (the TAO array of moorings in the Pacific, perhaps the largest scientific instrument ever built, has shown us the inner workings of el Nino). Molecular biology gives a remarkable tool for studying the function and evolution of ecosystems. Computer models of the climate system have become the centerpiece for ideas and observations, and computing power continues to increase steadily (though sometimes delayed by political constraints).

These new sensors and platforms give us eyes for viewing climate, computers and the internet give us a global central nervous system, but we also need the will to observe and understand the environment as it is assaulted by accelerating natural and human-induced change.

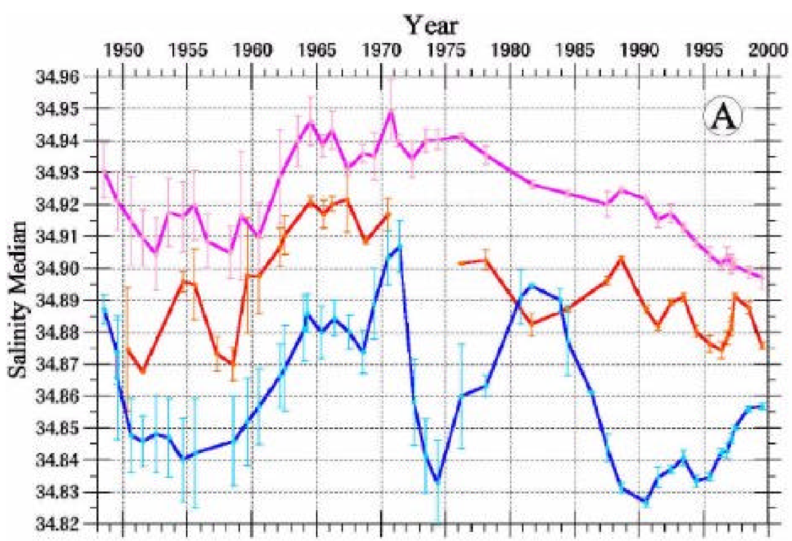
Rhines figures



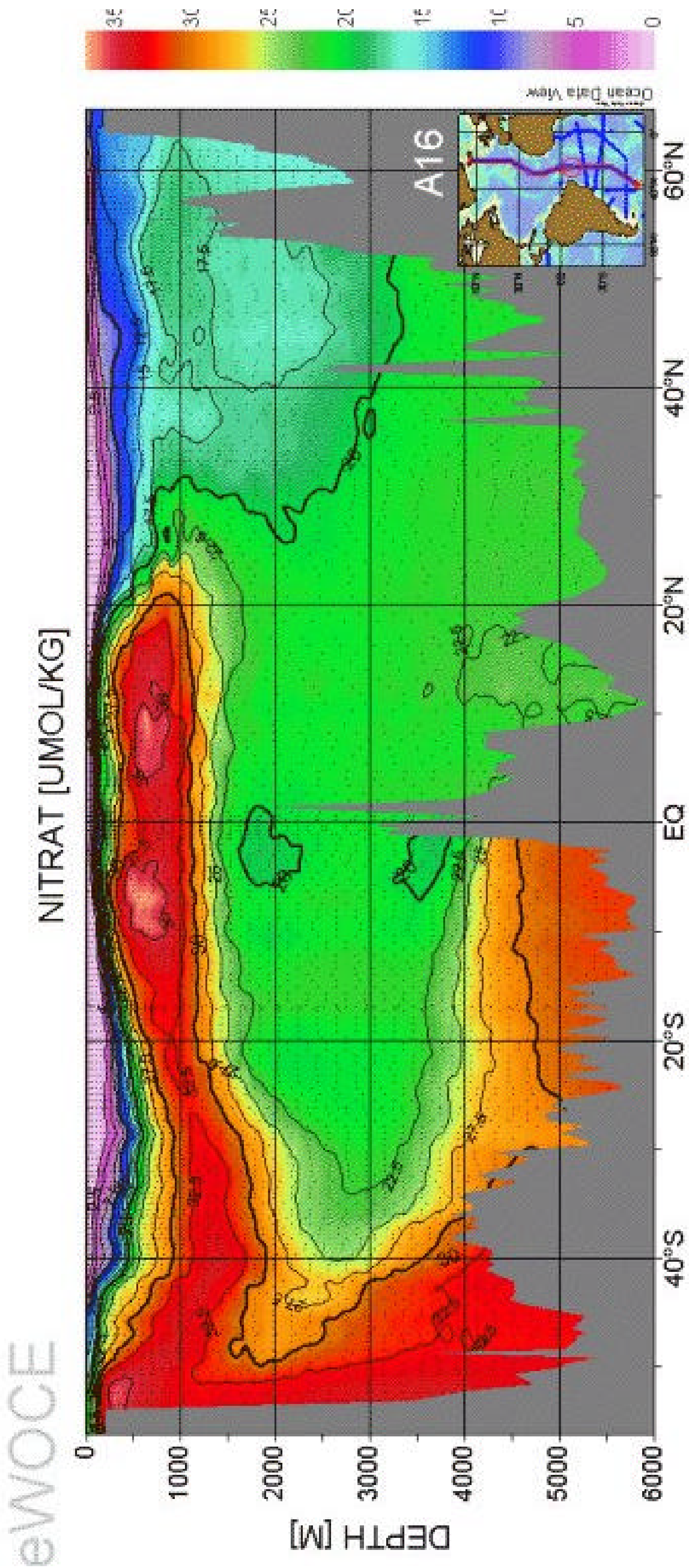
Currents and upwelling of cold, nutrient rich water along the US west coast
Sea-surface temperture (Oregon State University)



Evidence of a red tide on the West Florida Shelf:
Nov 1978, red = chlorophyll a > 3 µg/l (Florida Marine Inst.)



Northern Atlantic (Labrador Sea) salinity at three depths (2000m, 3500m, 1500m top to bottom). Salinity declines as fresh water input at the surface has increased with intense, cold forcing by the North Atlantic Oscillation.
I. Yashayaev, J. Lazier Bedford Inst. of Oceanography, P.Rhines (Univ. of Washington)



Dissolved nitrate in the Atlantic Ocean, along a section from Antarctica (left) to Iceland. High concentrations of this nutrient occur deep in the ocean, and in the Southern Ocean. Near the surface nitrate is almost absent, evidence of active ecosystem growth at the top of the ocean. The global ocean circulation must bring nitrate up to the surface, and controls the distribution of life (WOCE program).